

FURLING WORKSHOP AT THE NWTC – Day 1
July 14, 2000

Participants

- University of Colorado-Denver - Jan Bialasiewicz
- NREL - Gunjit Bir , Marshall Buhl, Dave Corbus, Jason Cotrell, Trudy Forsyth, Scott Larwood, Hal Link, Xabier Munduate, Kirk Pierce, Scott Schreck, Brian Smith, Peter Tu
- Windward Engineering – Dean Davis, Craig Hansen
- GEC – David Malcolm
- Bergey Windpower – Tod Hanley
- Southwest Windpower – Dave Snowberg
- AOC/WindLite – Mark Young

Presentations were made as listed below. All of the presentations can be found on the furling list server for more detailed review. Discussions were based on the presentation materials and are not recorded here. However, a detailed discussion occurred on Day 2 and those discussions are listed later in these minutes.

- 9:00am Opening and Introduction - Trudy Forsyth & Marshall Buhl
- 9:15 Modeling of yawing and furling behavior - Al Eggers
- 10:00 Results of the Synergy turbine modeling comparison to test data - Dean Davis
- 10:45 Aerodynamic loads on the yaw/furled rotor - David Malcolm
- 11:30 Modeling a Bergey-Type furling wind turbine - Marwan Bikdash
- 12:15 Lunch
- 1:15 Results of the Whisper 900 furling model and testing in Spanish Fork - Dean Davis
- 2:00 Bergey 40kW analysis and the sensitivity to various modeling assumptions – Craig Hansen
- 2:45 Summary of modeling of WindLite truck test data - Marshall Buhl
- 3:30 An overview of NASA-Ames test and future data - Scott Schreck
- 4:00 Wake measurements of the Unsteady Aero Experiment turbine in the region of a tail vane - Scott Larwood

FURLING WORKSHOP AT THE NWTC –Day 2

July 15, 2000

Participants

- NREL - Marshall Buhl, Trudy Forsyth, Scott Larwood, Kirk Pierce, Brian Smith
- Windward Engineering – Dean Davis, Craig Hansen
- GEC – David Malcolm
- Bergey Windpower – Tod Hanley
- Southwest Windpower – Dave Snowberg
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Executive Summary

The need for a better understanding of furling and yawing motion of small wind turbines is clear. The presentations, which occurred on Day 1, demonstrated that most participants were struggling with modeling of small wind turbines. This is with one exception and that is the work being done by Windward Engineering (C. Hansen and D. Davis) in modeling the Synergy turbines and the Whisper 900. The conclusion is that the aerodynamic input files need to better replicate the phenomenon of induction affects in skewed wakes.

After identification of this shortcoming, Day 2 was spent reviewing approaches to help understand the basic physics as well as getting some data to improve the modeling capabilities. Those approaches or recommendations will be summarized here with detailed meeting minutes following this section.

How do we get better aerodynamic understanding?

- ‘Mine the NASA/Ames data’ was a resounding recommendation. In reducing and reviewing these data, future data holes can be identified. Those data holes will help in identification of data requirements for future tests.
- Get more data on either a field test or wind tunnel test. While the wind tunnel test will get us data quickly when compared to field test data, the cost may be prohibitive. The needs for fundamental research will require data with maximal control of variables which leaves the wind tunnel test as the preferred alternate.
- Of course there is a preference by individual small turbine manufacturers to have their turbine used as the test specimen, it probably makes more sense to use a more ‘neutral’ turbine. In that way, if the Combined Experiment Research turbine may make the most sense, not only as a neutral turbine but additional data would add to the existing data and knowledge. However, significant turbine modifications will be required to change the turbine into a furling turbine. (Another thought was to use the Variable Speed Experiment turbine, [variable speed is typical of small wind turbines] and would also need to be modified to a furling turbine.)
 - The wind tunnel availability and choice of tunnel will drive the turbine size which will drive which turbine should be used as the test specimen.
- We currently know that the NASA/Ames data is limited for small turbine aerodynamic resolution due to the low TSR, low yaw rates, and use of a non-furling turbine.
- We should get noise data at the same time since that is also a design driver for small wind turbines.
- We need to develop some aerodynamic experts (Glauert’s grandson) to tackle this challenging problem. We may need to get some outside high level consultants.
- We could use CFD to help understand the flow issues and build a model that uses virtual probes to examine the wake.

- Finally, where is the crossover between large turbines that are actively controlled and small turbines that are passively controlled.

Al Eggers started off the Saturday morning Day 2 brainstorming session with the following comments;

- It is healthy that Turbine Research & Applied Research activities are closing ranks to solve the furling problem.
- This fascination with codes has limits; the analyst needs to know the limitation of current models for furling and yawing in order to improve them. This is of course hampered by induction effects in skewed wakes. These are some of the basic things that need to be understood by Applied Research people. One of the assumptions is not valid is that local flow is 2-dimensional. Therefore, understanding the numbers that are going into the code is more important than the code itself.
- There is a need to better understand the fundamental aerodynamics and the induction effects or skewed wake and the relationship to wake expansion. These limit the development of analytical tools to aid in design of small wind turbines. The uncertainties in performance of yawing and furling machines are such that pre-prototypes should have variable geometry (tilt, lateral offset) so that they can be fine-tuned during testing with guidance from the codes. And use the models to help fix the variable parameters to what you want.
- Other critical variables for testing include: yaw angle, furl angle, windspeed and wind direction, RPM, Thrust, Torque (derived), blade root movements. RPM is underlined due to it's criticality as a measurement.
- We need a disciplined test program (field testing)
 - Thrust can be very difficult to measure within a few degrees of accuracy.
 - We need center of thrust on the rotor disk (normal to the disk). This can be achieved by measuring yaw angles within a few degrees of accuracy. This will be difficult to synchronize with the wind. We don't want to introduce error through the addition of a DAS or instrumentation.
 - We could try testing by using streamers and watching them.
 - We need to test a machine at a site but if we wait for those results it will be too long. Maybe we should move along multiple paths.
 - The test needs to have the instruments designed into the wind system.
 - We can't get blade root moment and thrust on micro-turbines. Maybe we should test a small turbine in a wind tunnel and then field-test it. This could be used for code validation and understanding the physics.
 - For field-test data what metric would be needed to verify the data.
 - No load RPM (max RPM), furling wind speed
 - Results of the variable geometry trade-offs.

- How do we decide if we have good data?
 - Validate the coefficient of performance with wind speed.
 - Optimize the small wind turbine's furling power curve. This is complicated and should not be part of the first stage of testing.
 - Does the data meet the design criteria or system specifications? Does the data meet the design load and certification criteria?
 - These criteria may be in terms of annual energy production, power production, and passive control without being 'battleship' construction.
 - DAS challenges – The test engineer will solve this issue later.
 - SOMAT, ATLAS, ADAS, CAMPBELL, National Instruments
 - Need to resolve to 15P.
 - ADAS is too slow a sampling rate with filter roll-off problems.
- We need to inspect the turbines after several years of running for fatigue damage
- I recommend a rigorous pre-prototype test which support modeling development and then iterate on the prototype tests.
- Applied Research effort should focus on making better design tools using detailed testing [Scott Larwood → European tests, wake measurements in NASA AMES wind tunnel → MEXICO project]

Types of Testing

<u>Parameters</u>	<u>Variable Geometry</u>	<u>Prototype</u>	<u>Research</u>
Lateral Offset	x		
Tilt (Rotor, Tail)	x		
Loads		x	x
Detailed Inflow/Aerodynamics			x
Wind tunnel			x
Fundamental understanding of Flow and Wake in High Skewed Flow at Rotor and Downwind:			x
- Detailed Measurements			x
- Flow Visualization			
> Streamers	x	x	x
> Smoke	x	x	x

Possible solutions to gain more knowledge on furling/yawing include:

- AE Convert the Combined Experiment to a yawing and furling machine and get detailed data needed for models. "Piece of Cake". The advantage of this approach is that it builds on a significant amount of field and wind tunnel data.
- MB We need data sets that are post processed and reduced to a form that can be used with models and uncertainty analyses for each variable.
- DS Wind tunnel data is great. What information/reports is available now and what will be available in the future?
 - Some of the NASA/AMES results will be published through ASME '01.
- TH We need to understand the fundamentals of flow for unloaded rotor with high TSR. We also need wake data both upwind and downwind for the full flow field. I would like to see data for high yaw rates with an induction factor a of about 0.3. I would also like to see center of thrust vs. yaw angle.
- AE We could use the variable speed turbine (sister of the combined experiment rotor) which may be better than the combined experiment since it is variable speed. We would need to modify this turbine so that it yawed and furlled.
- It would be great to get wind tunnel data but that is more costly than collecting field data on prototypes.
 - We could also validate models (less expensive than the wind tunnel option) with high wind speed field data.
- CH We should complete these data analyses from the NASA/AMES test before moving onto something else – Mine the data we just got. We also need near term – robust, practical test programs for SWT prototypes that can validate models and verify designs. In the near-term we need use variable geometry and perform rigorous tests where the turbine changes are carefully documented with yaw angle, furl angle and RPM data. We should create a system to dump results into a database and improve our understanding as a group.

- For the long term, we should get information on what was covered by the NASA/AMES test and look for data points that would still be useful, i.e. angle of attack variations around yaw angles. Find these data holes and design another wind tunnel test to get those data.
- SL The data analyses plan and budget for the NASA/AMES test have been made with the furling problem in mind. We also need to identify the design drivers for noise on small wind turbines that need research and testing
- DM Mine the existing wind tunnel data. We need to have aerodynamicists look for better aero models/theories that can be used to improve codes.
- MY I think this has been a very helpful data exchange, learning session, and I hope that we will continue the dialogue. We need to apply research knowledge to improve the design tools. We should get aerodynamic experts to move the basic science forward and put those results into AeroDyn.
- We should get some acoustic data since this is such a domestic market driver. Also furling produces higher acoustic levels so this needs to be explored as well.
- Where is the cross over between large turbines with active control and small wind turbines with passive control? The future may be in actively controlling passive turbines.
- MB What are the analysis plans for the NASA/AMES test data. We could use data to validate CFD codes that can look at wake with virtual probes and more advanced computers.

Why use furling as an overspeed protection system? Who needs it?

- Best passive rotor control for small turbines
- Size limitation is when you can't afford to build the turbine hell for stout such that it can handle high yaw rates and extreme loading conditions
- Scaling effect and cost/benefit on passive/active
- CH For the Whisper 900 the down tower to grid cost (of Balance of System costs) are 3 times the turbine system cost (tower and turbine cost).
- AE The SWT group should make play for some trade-off studies being done in WindPACT, maybe with size limits of 10 kW to 150 kW.
- We should have more frequent furling discussions and meetings. We should also get international participation.
- Attach Scott Larwood's SWT/Furling bibliography to Meeting Minutes. (These will be made available on the furling server.)